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TWIST-FOUR EFFECTS IN DEEP INELASTIC NEUTRINO SCATTERING AND $SIN^2\theta_W$*

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ABSTRACT

In addition to the standard perturbative QCD corrections to deep inelastic scattering, there are nonperturbative twist-four corrections which behave like $1/Q^2$ relative to the $\ell n Q^2$ leading log corrections. We have calculated the twist-four, spin-one and spin-two corrections to σ_{NC}, σ_{CC}, R_ν and $R_{\bar{\nu}}$ using the following procedure: The bilocal product of the weak currents is expanded into local operators using the Wilson operator product expansion. The coefficient functions obey the renormalization group equations and, neglecting the anomalous dimensions of the operators, were calculated using perturbative techniques. The nucleon matrix elements of the local operators can then be evaluated assuming some quark confinement model. We found that twist-four, spin-two corrections to the neutral current neutrino scattering decreases $\sin^2\theta_W$ by about 1%. Taking into account the twist-four, spin-two corrections for the charged current cross section, we found that they give a dominant contribution to the ratio R_ν and increased $\sin^2\theta_W$ by about 0.5%. We also have studied the model dependence of our results and we have found that the twist-four, spin-two corrections to $\sin^2\theta_W$ are quite model dependent. The twist-four, spin-one corrections to the neutrino scattering were also calculated. These corrections come from two-quark, one-gluon operators and even at low Q^2 their contribution was found to be considerably smaller than the twist-four, spin-two corrections.

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The precise determination of $\sin^2\theta_w$, the fundamental parameter in the standard electroweak theory, requires an understanding of the corrections to the data from which $\sin^2\theta_w$ is to be extracted. We have previously calculated[1] some of the nonperturbative QCD corrections to the neutral current neutrino scattering cross section σ_{NC} and the ratio R_ν, which can be used to determine $\sin^2\theta_w$. We found the twist-four, spin-two corrections to the parton model to be given by[1]

$$\begin{aligned}\sigma_{NC}/\sigma_{CC}^{parton} &= \frac{1}{2} + \left(-\frac{424}{27}\frac{I_1}{M} + \frac{320}{27}\frac{I_2}{M}\right)\frac{\alpha_s(Q_o^2)}{Q_o^2} \\ &+ \left[-1 + \left(\frac{1360}{27}\frac{I_1}{M} - \frac{7040}{81}\frac{I_2}{M}\right)\frac{\alpha_s(Q_o^2)}{Q_o^2}\right]\sin^2\theta_w \\ &+ \left[\frac{20}{27} + \left(-\frac{4192}{81}\frac{I_1}{M} + \frac{256}{3}\frac{I_2}{M}\right)\frac{\alpha_s(Q_o^2)}{Q_o^2}\right]\sin^4\theta_w \quad , \end{aligned} \tag{1}$$

$$\sigma_{CC}/\sigma_{CC}^{parton} = 1 + \left(-\frac{848}{27}\frac{I_1}{M} + \frac{640}{27}\frac{I_2}{M}\right)\frac{\alpha_s(Q_o^2)}{Q_o^2} \tag{2}$$

and

$$\begin{aligned}R_\nu = \sigma_{NC}/\sigma_{CC} &= 1/2 + \\ &+ \left[-1 + \left(\frac{512}{27}\frac{I_1}{M} - \frac{5120}{81}\frac{I_2}{M}\right)\frac{\alpha_s(Q_o^2)}{Q_o^2}\right]\sin^2\theta_w \\ &+ \left[\frac{20}{27} + \left(-\frac{20,768}{729}\frac{I_1}{M} + \frac{49,408}{729}\frac{I_2}{M}\right)\frac{\alpha_s(Q_o^2)}{Q_o^2}\right]\sin^4\theta_w \end{aligned} \tag{3}$$

where $\sigma_{CC}^{parton} = (G^2/2\pi)ME$ is a convenient unit and we have integrated over all x and $Q^2 > Q_o^2$. Since, for singlet targets, weak isospin invariance alone requires $R_\nu = R_{\bar{\nu}} = 1/2$ for $\sin^2\theta_w = o$, eqs. (2) and (3) are implicit in eq. (1), providing an independent check on our calculations.[2] The model dependent radial integrals I_1 and I_2 have been numerically calculated for several quark confinement models of the nucleon.[3] If σ_{NC} [eq. (1)] is used to determine $\sin^2\theta_W$ the twist-four, spin-two QCD corrections are very model dependent and tend to decrease $\sin^2\theta_W$ by about 1%. However, if $\sin^2\theta_W$ is taken from measurements of R_ν, the QCD corrections are much less model dependent and, indeed, increase the value of $\sin^2\theta_W$ by only about 1/2%. This is a consequence of the dominant QCD correction cancelling in the ratio $R_\nu = \sigma_{NC}/\sigma_{CC}$ and the empirical fact that $\sin^2\theta_W$ is rather small, itself. (Recall $R_\nu \to 1/2$ as $\sin^2\theta_W \to 0$).

More recently we have investigated the twist-four, spin-one corrections to σ_{NC}, σ_{CC} and R_ν, which come from the contributions of the two-quark, one-gluon operators, and can be calculated using the QCD field equations inside the nucleon. These twist-four, spin-one corrections are opposite in sign for neutrinos and antineutrinos and, for singlet targets, they contribute an additional term to σ_{NC}

$$\delta[\sigma_{NC}/\sigma_{CC}^{\text{parton}}]_{\nu,\bar{\nu}} = \pm\,[\alpha_s(Q_0{}^2)/ME]\ln[2ME/Q_0{}^2][\tfrac{2}{3} - \tfrac{4}{3}\sin^2\theta_W]A_1{}^+/g(Q_0{}^2) \tag{4}$$

where

$$A_1{}^+ = -\,4\,\langle N|\int d^3x\,\bar{q}(x)\,\vec{\gamma}\,\gamma^5\,(\lambda^a/2)\,q(x)\cdot\vec{B}^a(x)|N\rangle \quad , \tag{5}$$

with $\vec{B}^a$ being the color magetic field, is a model dependent matrix element. We have previously calculated[4] $A_1{}^+/g(Q_0{}^2)$ for several quark confinement models. Clearly, the corresponding twist-four, spin-one correction to σ_{CC} is

$$\delta[\sigma_{CC}/\sigma_{CC}^{\text{parton}}]_{\nu,\bar{\nu}} = \pm\,[\alpha_s(Q_0{}^2)/ME]\ln[2ME/Q_0{}^2](4/3)\,A_1{}^+/g(Q_0{}^2) \tag{6}$$

and the subsequent additional correction to σ_{NC}/σ_{CC}[eq. (3)] is therefore

$$\delta R_{\nu,\bar{\nu}} = \mp [\alpha_s(Q_o{}^2)/ME]\ln[2ME/Q_o{}^2](81/80)\sin^4\theta_W A_1^+/g(Q_o{}^2) \qquad (7)$$

This twist-four, spin-one correction , while very model dependent, is quite small, typically 1%, compared to the twist-four, spin-two corrections, already included in eq. (3). We, therefore, conclude that, in spite of their substantial model dependence, the spin-one contributions can be neglected in comparison with the spin-two contributions to the twist-four QCD corrections to R_ν and $R_{\bar{\nu}}$.

In summary, we have shown that for purposes of determining $\sin^2\theta_W$ from neutrino scattering data using R_ν avoids much of the model dependence of the twist-four QCD corrections that are present in σ_{NC}. In fact, the spin-one corrections are entirely negligible compared to the spin-two contributions, which themselves need only be considered if $\sin^2\theta_W$ is to be determined to the 1% level of precision.

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